# Hydro-climatic extremes in a changing environment

*Foto: NVE, Henny van Lanen*

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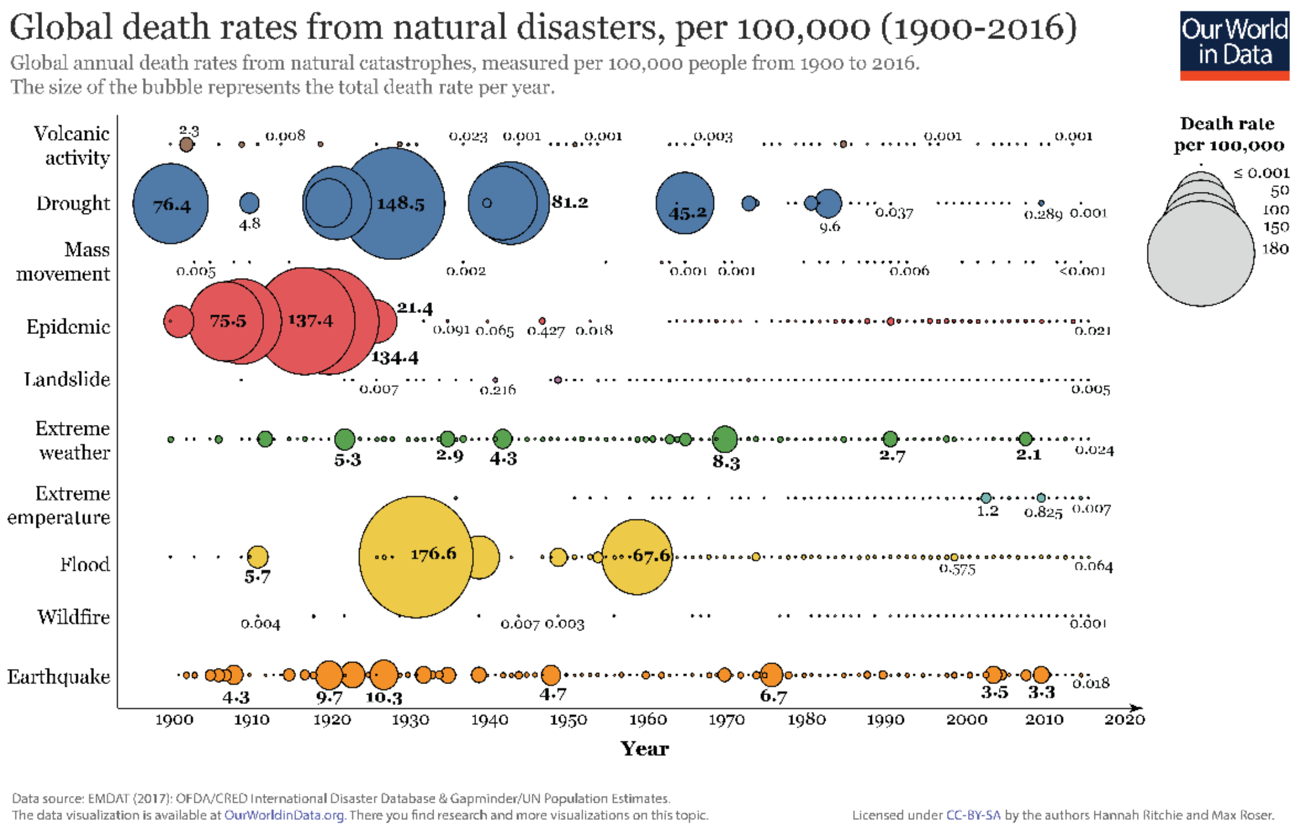
***5th Conference on Modelling Hydrology, Climate and Land Surface Processes***
*Lillehammer, Norway*
*17-19 September 2019*

UiO : Department of Geosciences
University of Oslo

# International disaster database EM-DAT



# International disaster database EM-DAT

**Total Number of People Affected by Disaster Type (2018 vs. average 21st Century)**

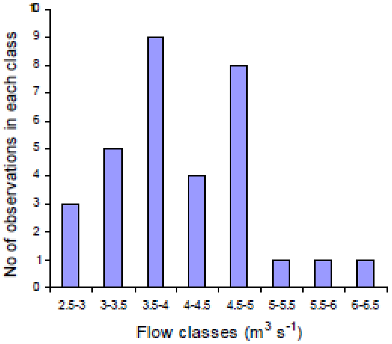
| Event | 2018 | Average (2000-2017) |
|---|---|---|
| Drought | 9,368,345 | 58,734,128 |
| ★ Earthquake | 1,517,138 | 6,783,729 |
| ★ Extreme temperature | 396,798 | 6,368,470 |
| Flood | 35,385,178 | 86,696,923 |
| Landslide | 54,908 | 263,831 |
| Mass movement (dry) | 0 | 286 |
| ★ Storm | 12,884,845 | 34,083,106 |
| Volcanic activity | 1,908,770 | 169,308 |
| Wildfire | 256,635 | 19,243 |
| **Total** | **61,772,617** | **193,312,310** |

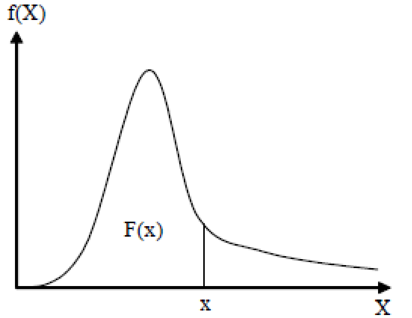
Source: EM-DAT (International Disaster Database)

★ Top three economic losses

«It is **likely** that something **unlikely** is going to happen» (Aristotle, 384-322 BC)

# Frequency analysis




- Involves several steps
  - Define the variable/index to be studied
  - Select the extreme events (min/max – AMS/PDS)
  - Select the probability distribution and estimate its parameters
  - Estimate the extreme event (design value) for a given return interval
- The uncertainty of the estimated extreme depends strongly on sample size and assumptions made
- Traditionally based on the assumption that the data are *independent* and *identically* distributed (iid)
- Non-stationary methods include univariate and bivariate models, with distribution parameters varying with time.

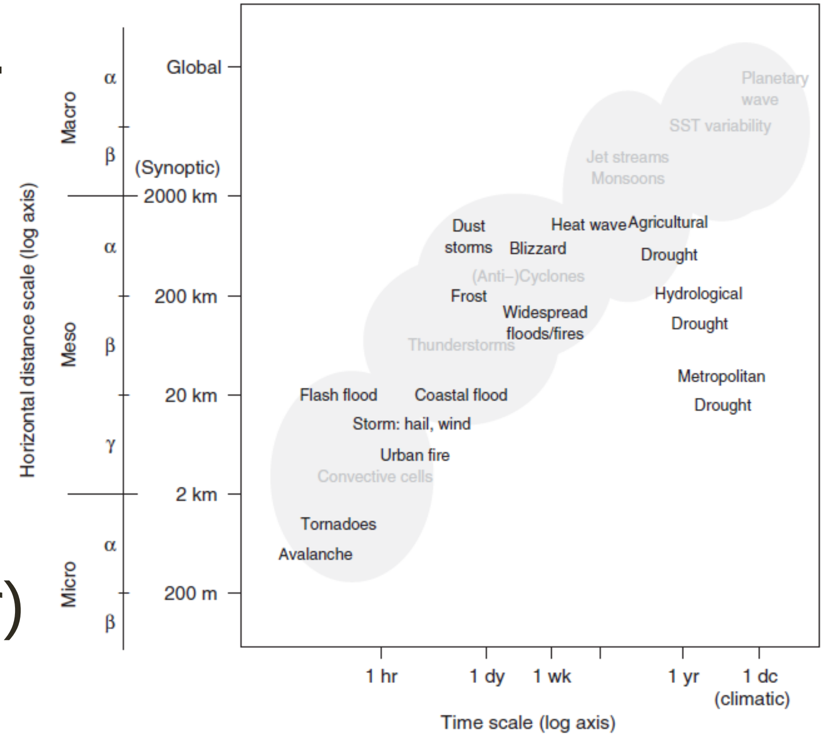
# Analyses of exteme events

- Extreme value analysis (frequency analysis)
  - Variable and index
- A changing environment
  - **Past**: Historical time series, reconstruction, paleo
  - **Present**: Changes and trends, event-based analysis
  - **Future**: projections

How likely?

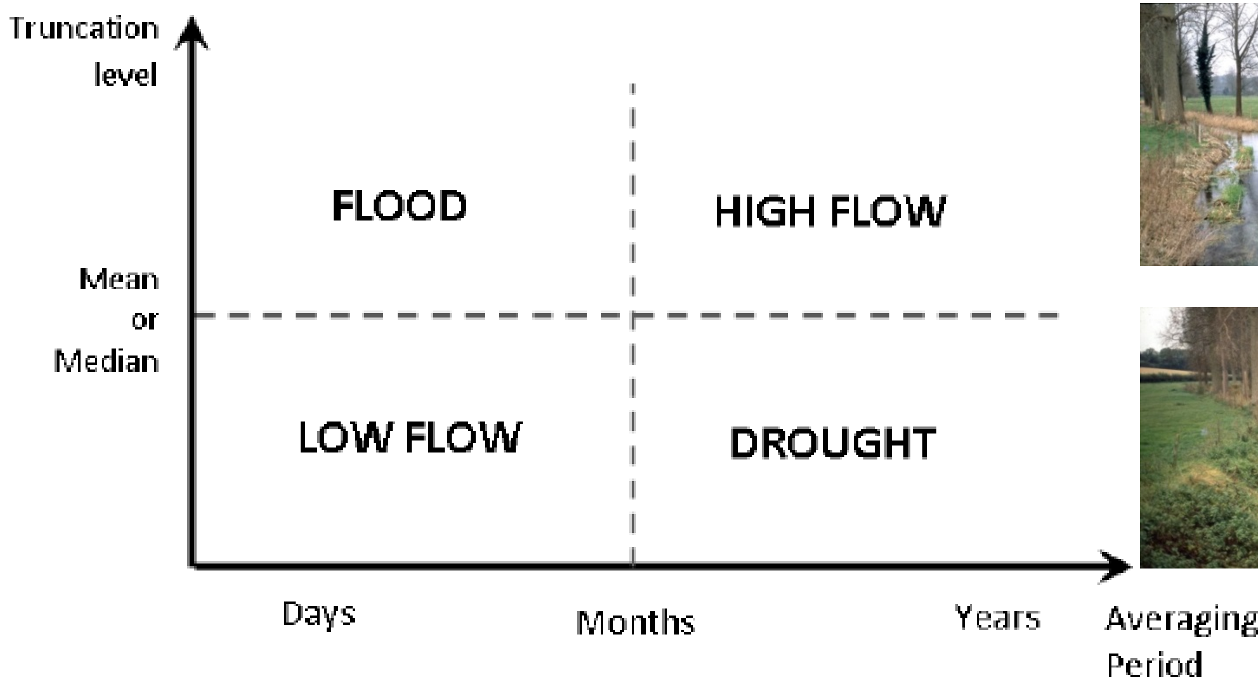
# Hydro-climatic extremes

- Extreme weather events, e.g.
  - exteme heat and cold
  - heavy rainfall or snowfall
  - meteorological drought
  - storms
- Extreme hydrological events (streamflow and groundwater)
  - hydrological drought
  - flood




*Leonard et al., 2013*

# Classification of hydrological events




*Dracup et al. (1980)*

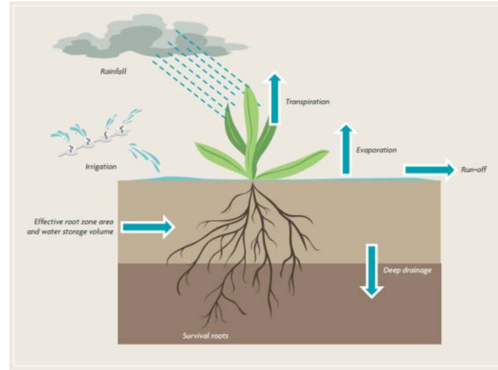
*photo: Henny van Lanen*

# Flood and low flow marks


**Flood mark** in *Ottadalen Storofsen*
*Kilde: Norsk kulturarv*

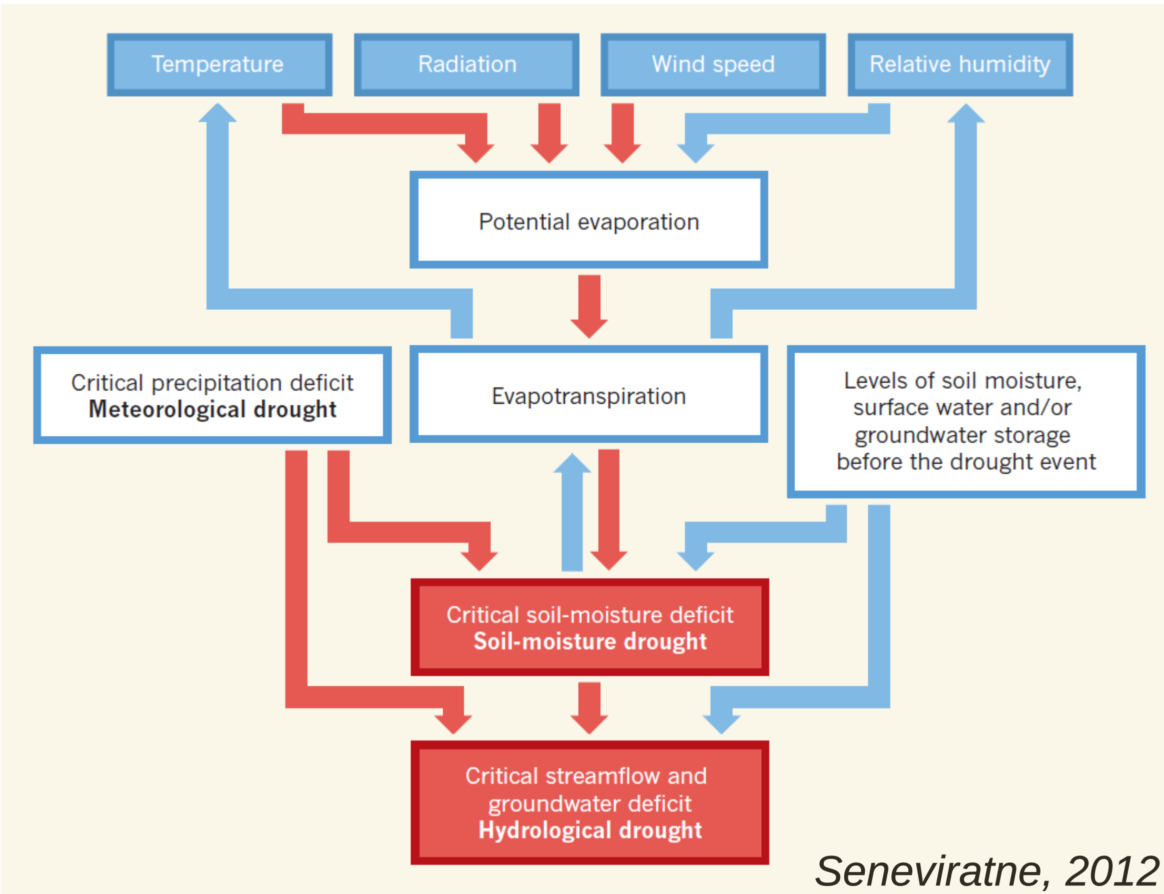
**Hunger Stone** at Elbe; Decin, Tsjekkia
"Wenn du mich siehst, dann weine"
Kilde: Wikipedia; AFP/RSS

# Flood

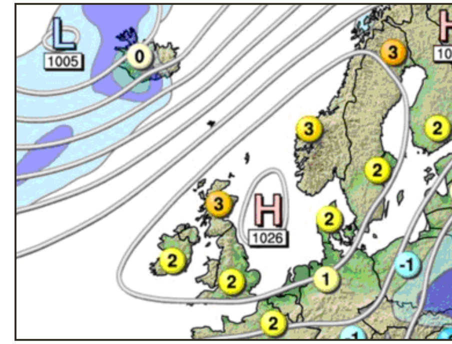



- **Process type** *(Merz & Blöschl, 2003)*
  - Short-Rain floods
  - Long-rain floods (high flows, groundwater flooding)
  - Flash floods
  - Rain-on-Snow floods
  - Snowmelt floods
- **Variable**
  - Streamflow/groundwater level or discharge/runoff
  - Innudated area (water level; river network)
  - Affected area (regional to national scale)

# Different types of drought

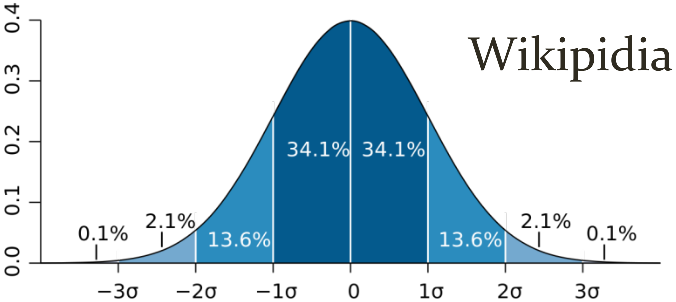



*Seneviratne, 2012*




# Standardised Indices - Wet and Dry

**SPI** – transform accumulated monthly precipitation (P) to the standard normal distribution (std N)




Wikipidia

**SPEI** – transform accumulated precipitation less potential evapotranspiration (P-PET) to the std N

- A more complete estimate of available water
- Relies on choice of PET algorithm

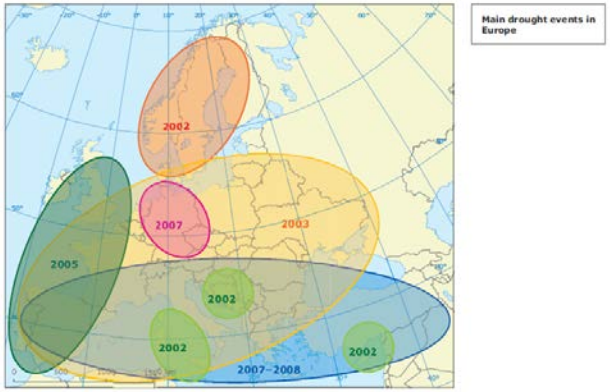
**SPI/SPEI**

- recommended by WMO
- different time lags (1, 3, 6,12, .. months)
- Choice of distribution at the regional scale (SPI, SPEI)

# Hydrological Drought

- **Process type**
  - Soil moisture drought
  - Streamflow (low flow or drought)
  - Groundwater drought
  - Winter/seasonal drought

- **Variable**
  - Soil moisture content (at-site)
  - Streamflow/groundwater level or discharge (at-site)
  - Drought affected area (soil moisture, streamflow or runoff, groundwater level; regional to continental scale)




Source: ETC-LUSI, adapted from Tallaksen, 2007.

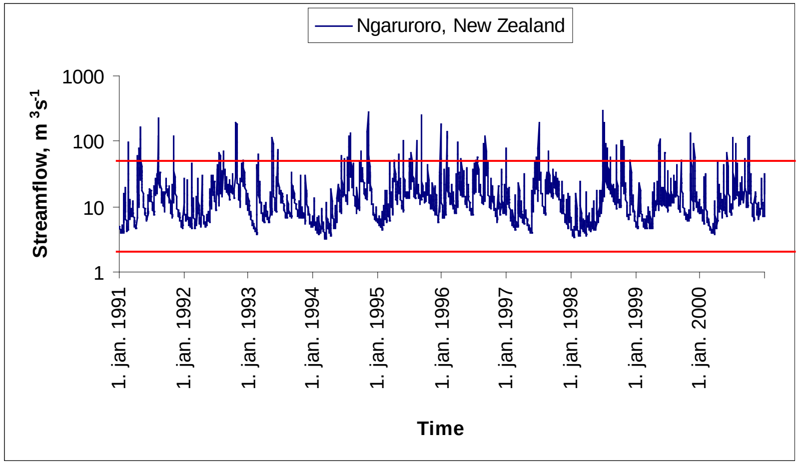
# Hydrological extremes - indices

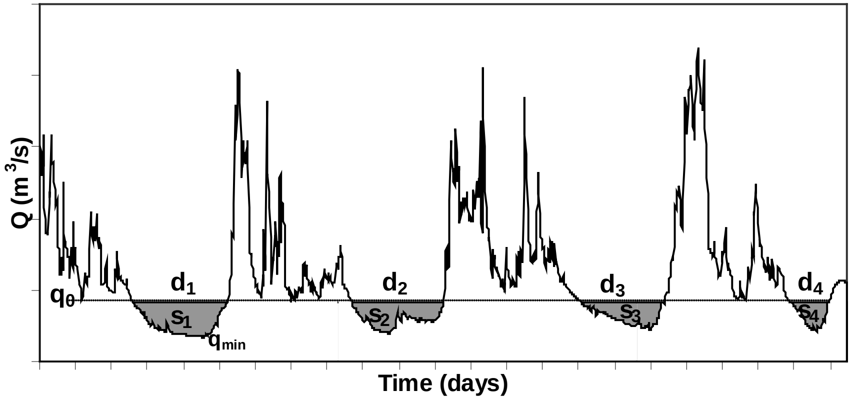
- High and Low flow characteristics

  (max or min values)
  - AMS or PDS

- Volume characteristics (maximum values)
  - duration
  - surplus or deficit volume (severity)

- Areal indices

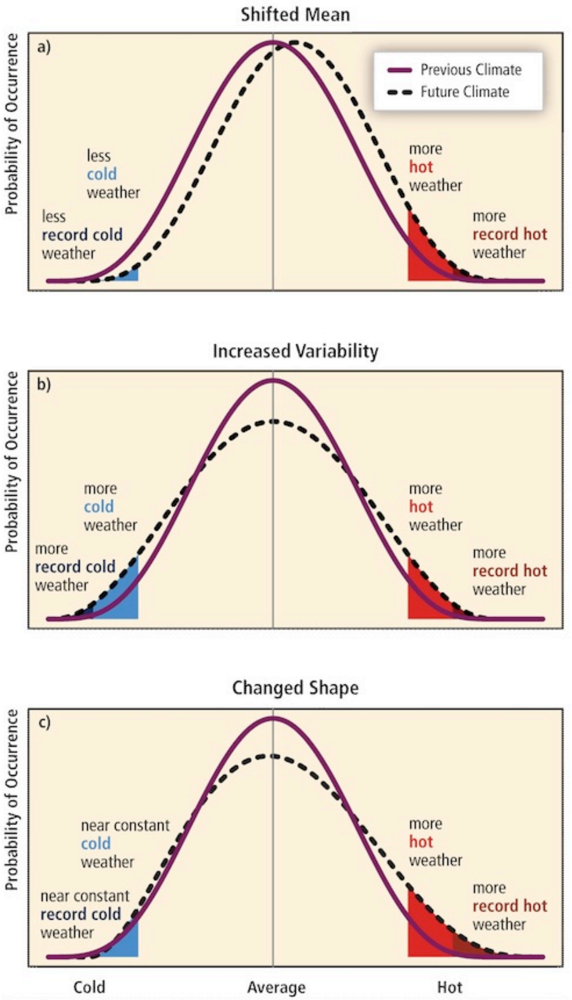



*Tallaksen and van Lanen, 2004*

# A changing environment

- Changes in the tails of the probability distribution or in the extreme value distribution itself
- Detection of changes and trends
  - Mean and extremes
  - Based on observations
- Use of climate models simulation in detection and attribution of change
  - Compare observed changes with climate projections




*Temperature; IPCC, 2012*

nature climate change

Letter | Published: 05 August 2012

## Increasing drought under global warming in observations and models

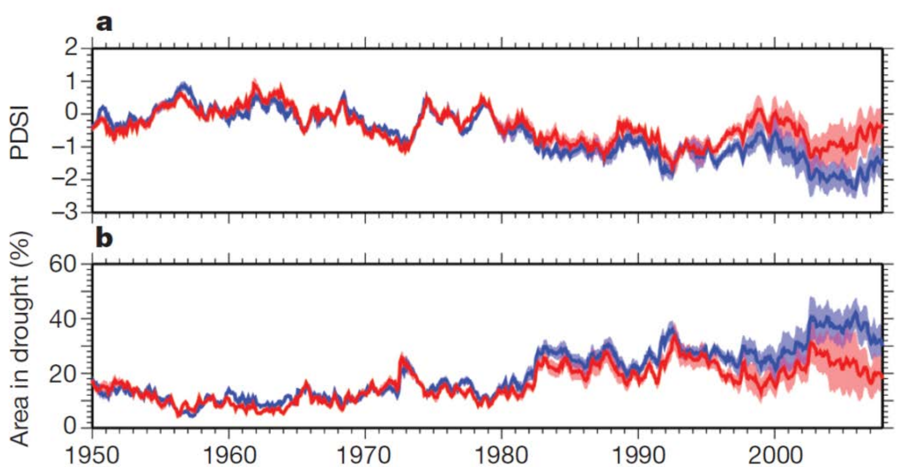
Aiguo Dai

nature
International journal of science

Letter | Published: 14 November 2012

## Little change in global drought over the past 60 years

Justin Sheffield, Eric F. Wood & Michael L. Roderick




Temp
Pen-Mon

**Figure 1** | **Global average time series of the PDSI and area in drought.**

*Sheffield et al., 2012*

nature
International journal of science

News & Views | Published: 14 November 2012

Climate science

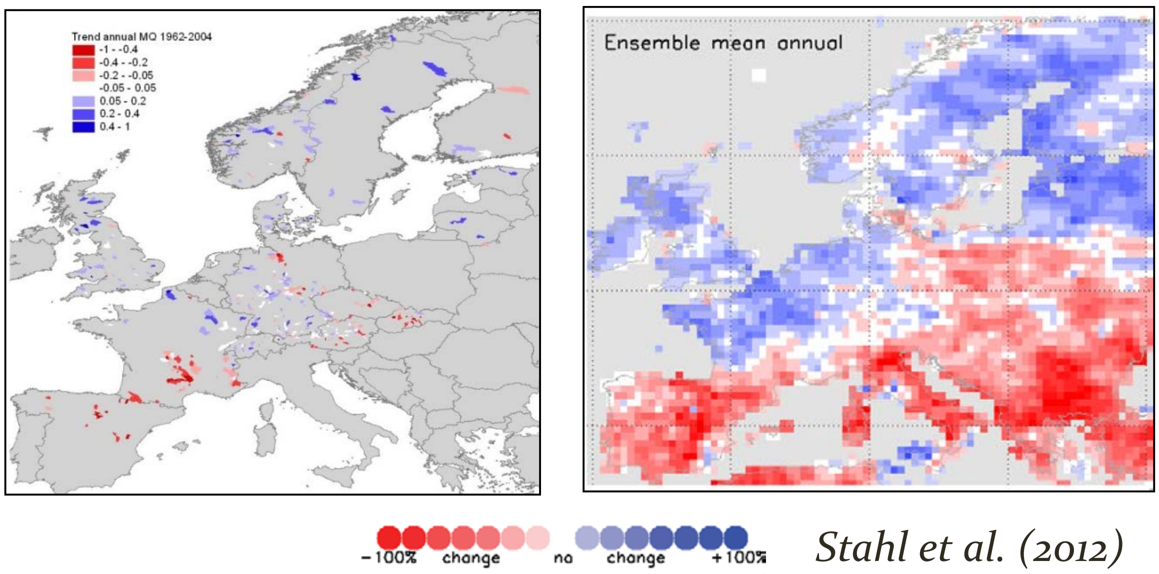
## Historical drought trends revisited

Sonia I. Seneviratne

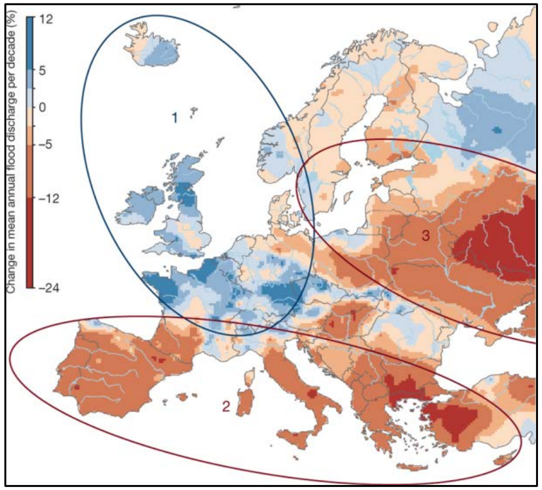
# European-scale trends in mean annual streamflow and flood

1962 – 2004

1960 - 2010



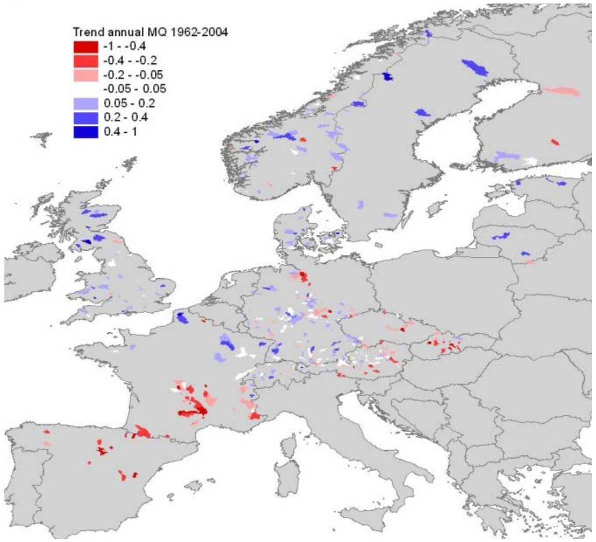

*Stahl et al. (2012)*



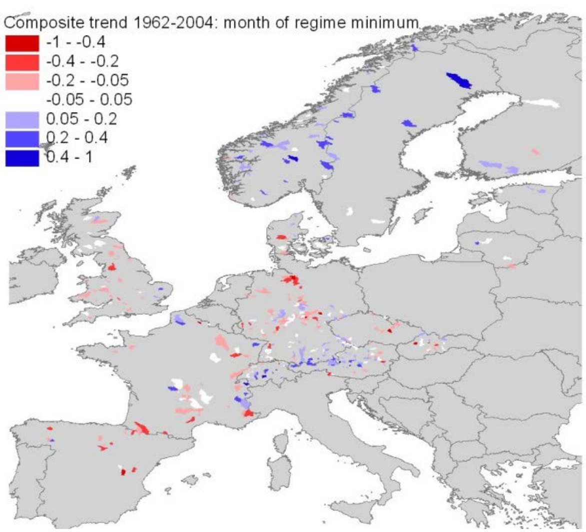

*Blöschl et al. (2019)*

# Trends in monthly minimum flow

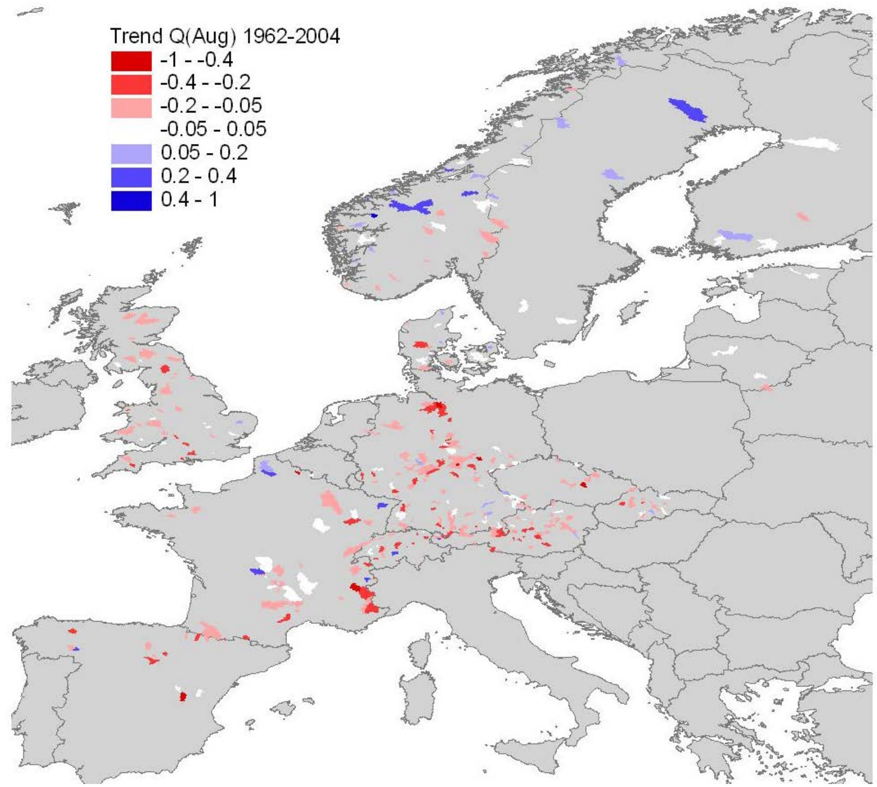
Annual flow




Month of the min flow




## August flow

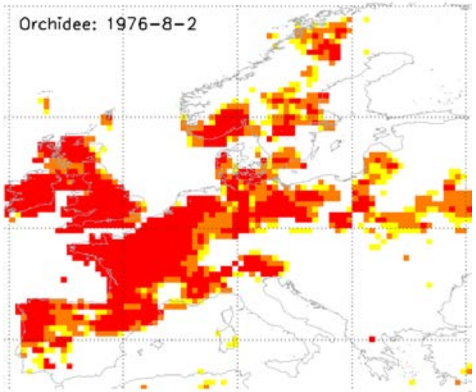



*Stahl et al. (2010) HESS*

# Trust in model simulations


- Do off-line global (hydrological and land surface) **model simulations** provide an acceptable dataset of historical variables such as soil moisture and runoff for analysis of hydro-climatic extremes?

- **Example study**: Analysing the extent and timing of large-scale hydrological droughts in Europe as simulated by a suite of off-line models



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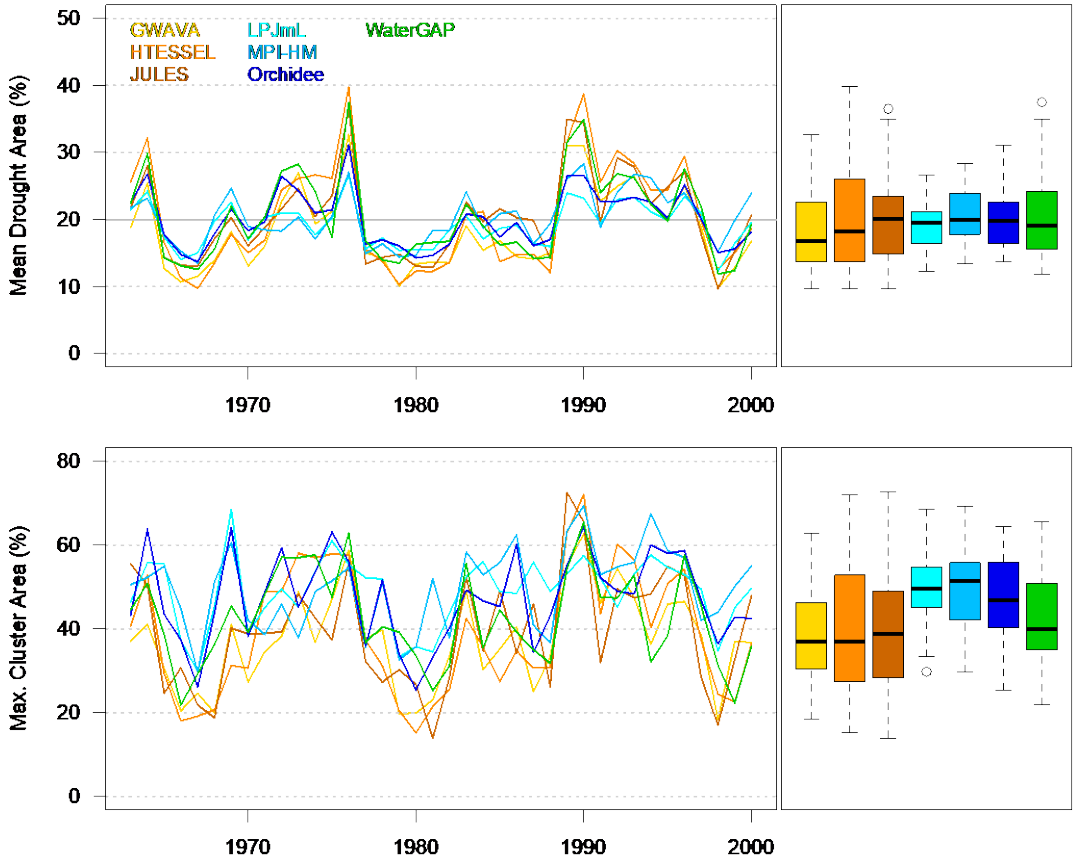
# Area in drought – annual indices

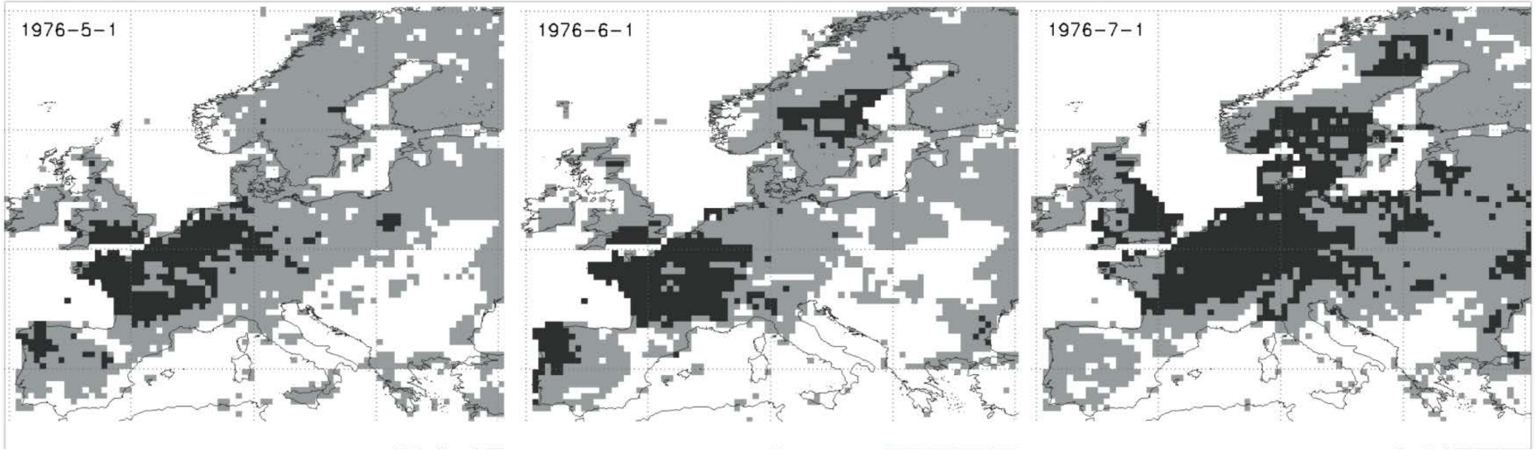



*Tallaksen and Stahl, 2014*

# Drought development in space

Grid cells in drought on a given day;
all (**black**), some (grey) or none (white) of the seven models

1 May 1 June 1 July 1976




*Tallaksen and Stahl, 2014*

Strongly urge for **more validation studies** to improve future projections and learn the current limits of model simulations.

# A changing environment – Future

HOSTED BY THE GUARDIAN

*Seager and Harding, J. Cl*

Previous

## Global warming makes d on earlier, faster, and ha

A new study tries to separate natural and drought

Yemenis walk through a drought-affected dam on the a city is running out of water and many relief agencies capital city in the world to run out of a viable water sup Arhab/EPA

euronews. Europe World More Programmes

Home > News > World > Drought and floods will become more common as global warming causes weather to 'stall'

WORLD

## Drought and floods will become more common as global warming causes weather to 'stall'

11 COMMENTS

By Claire Heffron • last updated: 21/08/2018

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TEXT SIZE Aa Aa

Scorching summer heatwaves and floods are set to become more extreme in the northern hemisphere as global warming makes weather patterns linger longer in the same place.

According to a study published by Nature Communications, growing temperatures in the Arctic have slowed the circulation of the jet stream and other giant winds, affecting pressure fronts across continents.

nature climate change

## on in the world's dry and

ander[1], Paul A. O'Gorman[2] and Nicola Maher[1]

extremes should scale with low-level atmospheric moisture content, which increases at a rate of about 6–7% $K^{-1}$ warming according to the Clausius–Clapeyron relationship[18]. However, the rate of increase of precipitation extremes is affected by multiple factors,

*enko Mykhailo / Fotolia*

# Analyses of exteme events

- Extreme value analysis (frequency analysis)
  - Variable and index
- A changing environment
  - **Past**: Historical time series, reconstruction, paleo
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  - **Future**: projections

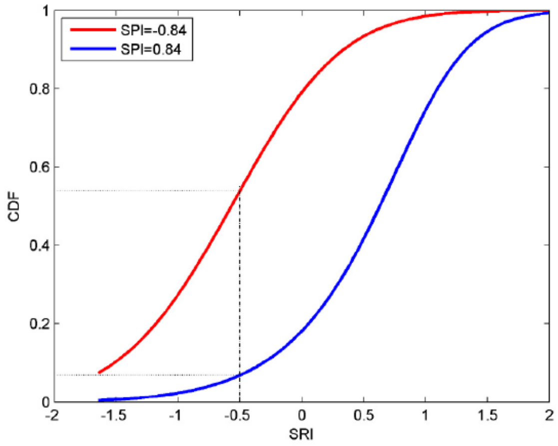
How likely?

- Generating processes (causes)
- Compound events and extreme impacts
- Attribution

Something unlikely?

# From extreme hazards to impacts

- Natural disasters caused by extreme weather events are often the result of a combination of (interrelated) factors - **compound events** - rather than a single variable being in an extreme state




*Hao et al., 2018*

- Need to better understand how climate variables combine to produce **extreme impacts**

- Climate change may cause an unusually combination of factors leading to **unexpected impacts** and hazards that have not previously been experienced.

# Compound event

Is an **extreme impact** that depends on multiple dependent variables or events

*Leonard et al. 2014 Wires Climate Change*

Three key characteristics:

- the extremeness of the impact
- the role of multiple drivers
- the role of statistical dependence

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# How do we understand impacts?

- (Negative) impacts on the environment, society and economy
- Impacts are not necessarily linearly related to the natural hazard and small changes in climate may produce large changes in impact severity
- How do we model impacts?
  - Model-based approach
  - Impact-based approach

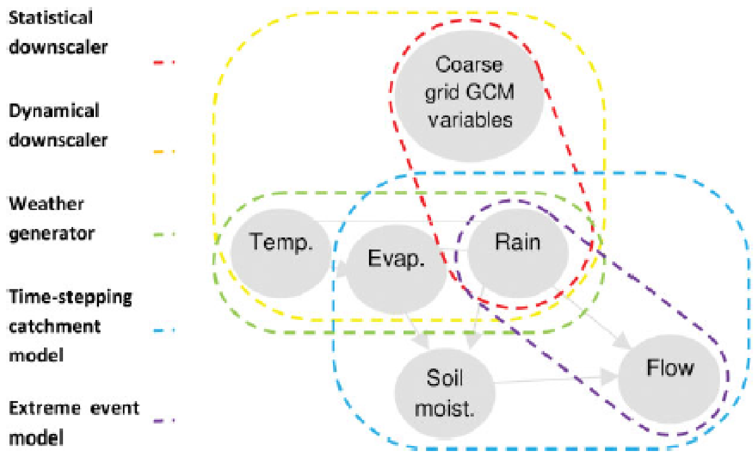


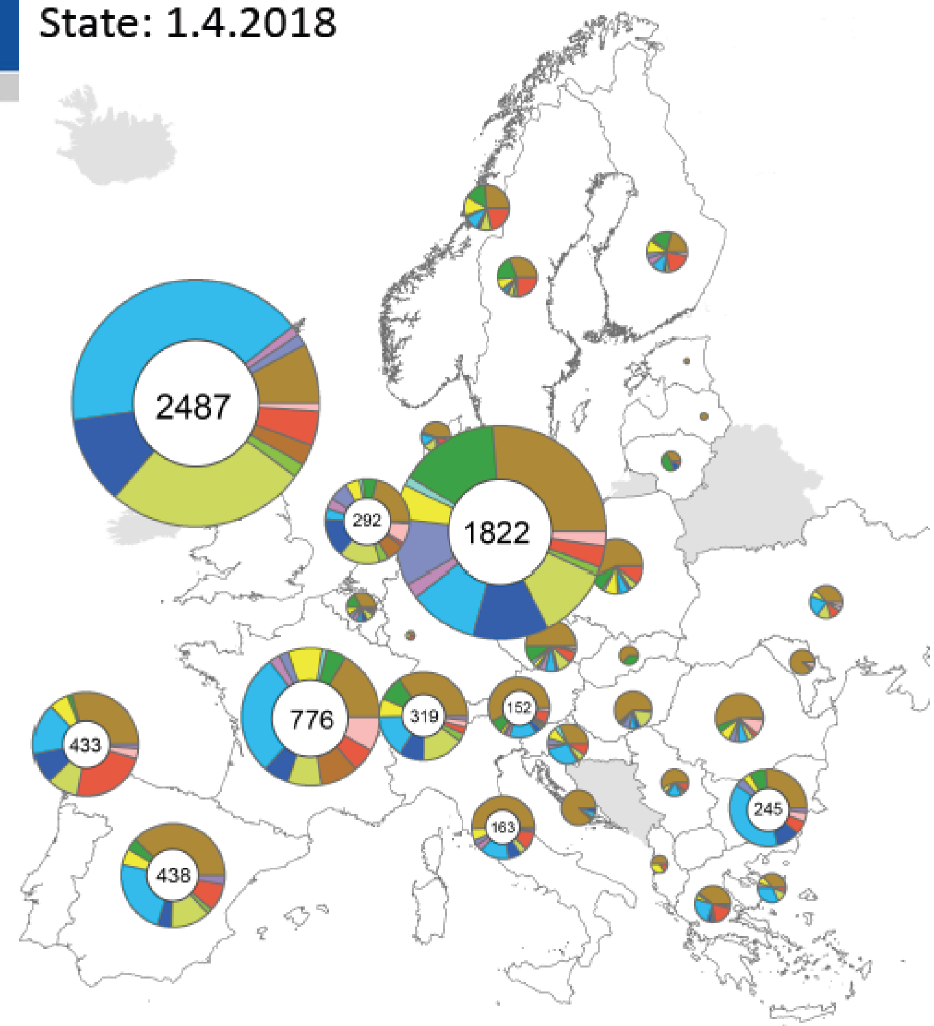

**FIGURE 7** | Comparison of modeling methods that relate climatic and hydrologic variables.

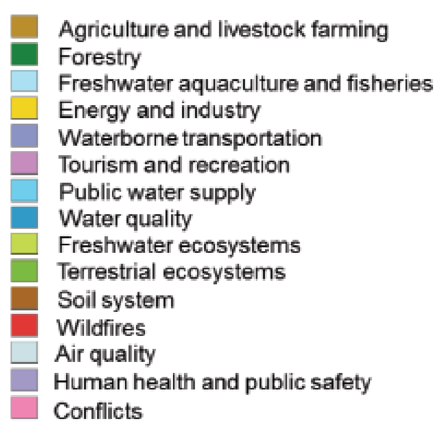
*Leonard et al., 2013*

# Current contents - Europe

State: 1.4.2018

- EDII – European Drought Impact Inventory
- Hosted at the European Drought Centre (EDC) website
- ~ 6000 'impact reports' from 38 countries



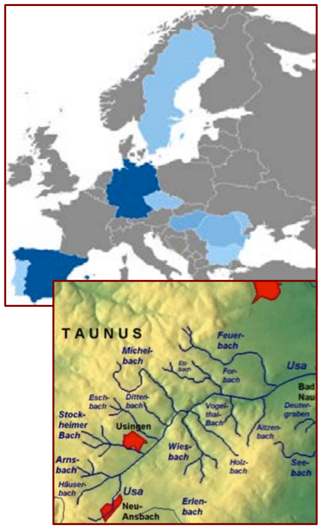




*Stahl et al. (2016)*

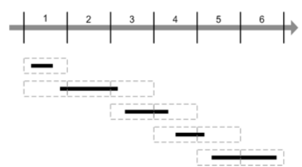
*Online EDII: http://www.geo.uio.no/edc/droughtdb/index.php*

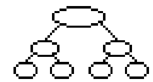
# Archiving impact reports

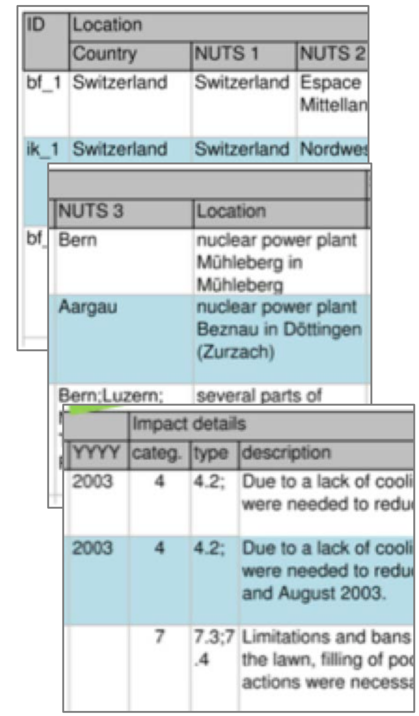
Source of information → Location → Impact Occurrence → Impact Categorization → The Archive








- Collection is tedious
+ Textual evidence links cause (drought) and effect (impact)
+ - Coding guarantees consistency, but restrictive → **keep Text!**

# Drought – Anecdotal evidence

Aftenposten, 1933

Østlandet varmest i Europa.

Allerede for en måneds tid siden begynte klagene over tørken på Vestlandet å gjøre sig gjeldende. Det hadde ikke været så tørt i manns minne, og selv gamle folk kunde ikke huske noget lignende. Slike uttalelser er så almindelige, at man som oftest ikke bør tillegge dem nogen større verdi. Gamle folk husker jo ofte svært dårlig, og manns minne er som regel dårligere enn en kvinnes. Men nu har tørken varet i en måned til og er mange steder av næsten katastrofal art. Vestlandets landbruk er jo innstillet på meget regn, og når der så i to måneder i den viktigste veksttid bare kommer små mengder, så er der virkelig grunn til å snakke om en helt usedvanlig tørke. For bare

net eiendommelig fenomen i forbindelse med den siste tids vær. Vi har nemlig i første halvdel av juni iår hatt en værtype som i almindelighet først setter inn i juli måned. Disse voldsomme, lokale tordenbyger over innlandsdistriktene som vi i de siste dager har merket ganske bra også i Oslo, burde slett ikke innfinne sig så tidlig på året. Vi har i det hele fått høisommeren inn over oss uten nogensomhelst overgang; Østlandet har således stort sett i juni været det varmeste sted i Europa. Denne trykkende varme i forbindelse med innsig av kold luft i høiden har gitt oss disse instabile luftmasser som rett som det er gir tordenbyger.

Takket være de lokale regnbyger har store strøk av Østlandet fått rikelig med regn. Ved Kutjern på Gjøvikbanen er der således i de siste 8 dager falt 76 mm. Til sammenligning kan anføres at den normale nedbør i Oslo for hele juni er

- Agriculture adapted to frequent rainfall
- Large spatial extent
- Convective vs frontal prec.
- Cause of the drought
  - Distribution of High and Low pressure centres
  - Likely influenced by ocean temperatures
- Research focus
  - Assess the interaction between the ocean and the atmosphere to better predict the weather.

# Best-predictors for impacts

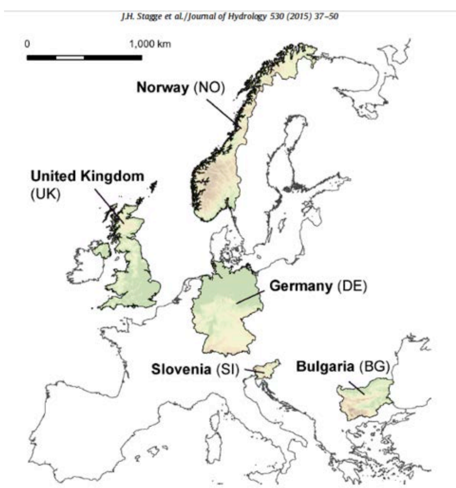



Fig. 1. Countries with drought impact models.

## Four sectors

- Agriculture
- Energy and industry
- Water supply
- Freshwater ecosystems

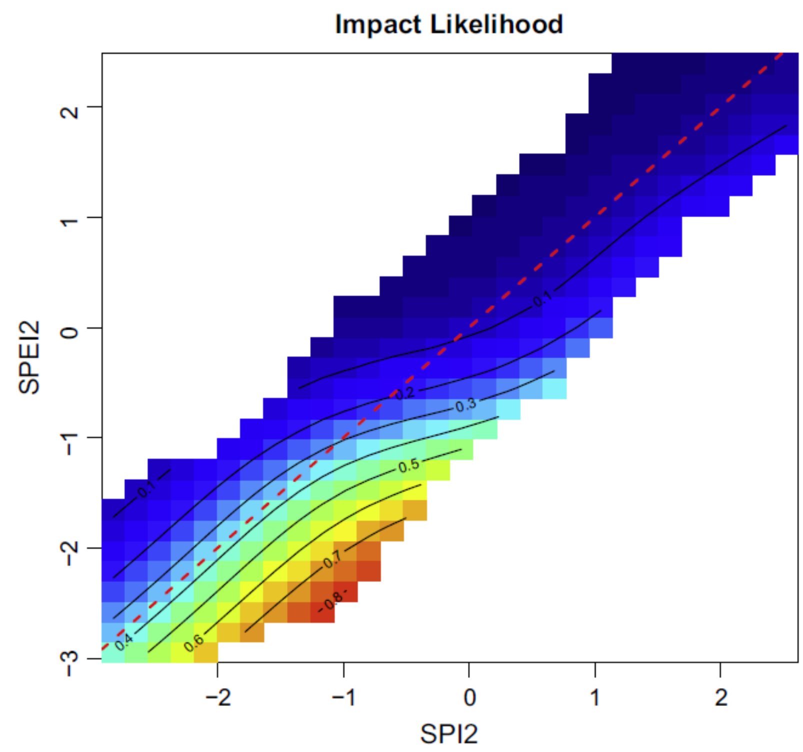
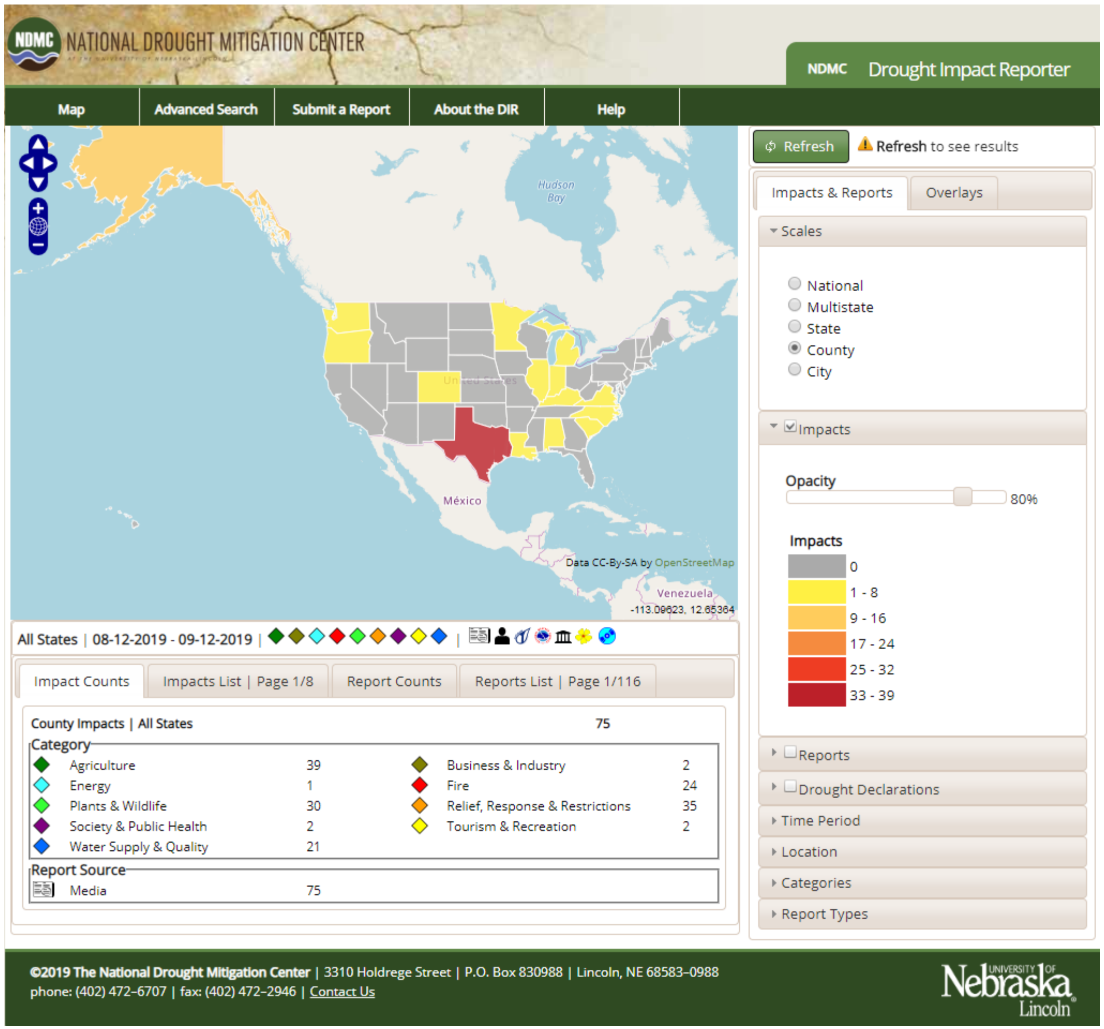



**Fig. 6.** Agricultural drought impacts: SPI2/SPEI2 interaction term for Slovenia. Predicted impact likelihood is shown in color, with red corresponding to high likelihood (≈100%) and blue corresponding to low likelihood (≈0%). Percent likelihood is also shown as contour labels. (For interpretation of the references to

*Stagge et al. 2015 JoH*

# US Drought Impact Reporter



# Impact-based forecasting / projections

WMO Guidelines on
Multi-hazard Impact-based
Forecast and Warning Services

Gap between forecasts and warnings of extreme hydrometeorological events and an understanding of their potential impacts.

*WMO-No. 1150, 2015*

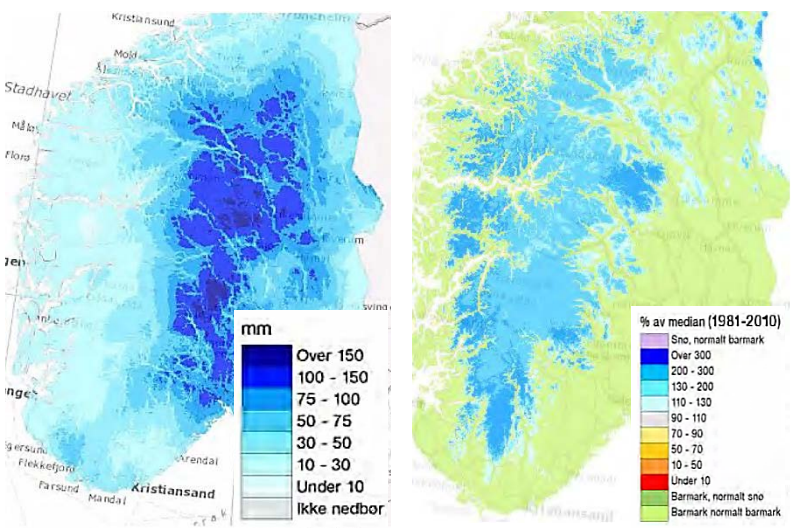
# Compound events – Illustrations

| When | Where | Multiple drivers | Extreme impacts |
|---|---|---|---|
| May 2013 | Kvam Norway | Heavy rainfall and snowmelt | Severe impacts due to flooding |
| Dec 2013 – Jan 2014 | UK | Series of rainfall event | Severe impacts due to flooding |
| Dec 2013 – Jan 2014 | Western Norway | Dry, windy, lack of snow | Severe wildfires |
| Summer 2018 | Northern Europe | Dry and hot summer | Heatwave and severe drought impacts |
| 21th C | Arctic | Winter warming, frost spells | Large-scale vegetation damage |
| ~ 2019 | Southern Norway | Heavy rainfall, initial conditions | Severe impacts due to flash floods |

# Rain-on-snow (ROS) event 2013

- Devastating spring ROS floods occurred in Kvam, southern Norway, ~1bn NOK damages
- A large rainfall event 21-23rd May

Rain and snowmelt 17-23 May




*Roald (2015) NVE report 21*

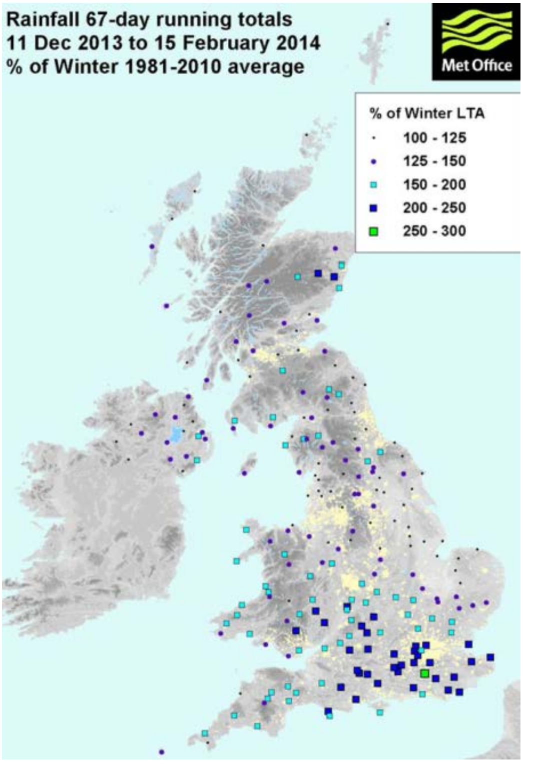
*Photo: vg.no*

**Ref.** Pall et al., talk

# Winter 2013/2014

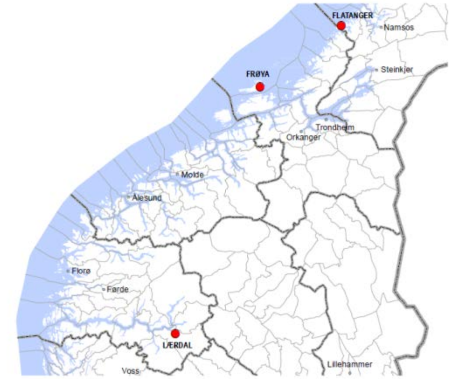
- Prolonged rainfall over much of Britain in December 2013 and January 2014 led to high river flows and flood alerts.

- In some areas the wet weather lingered as groundwater flooding.




*NERC, Wallingford, UK*

# New and emerging hazards




Northwestern Norway, January 2014

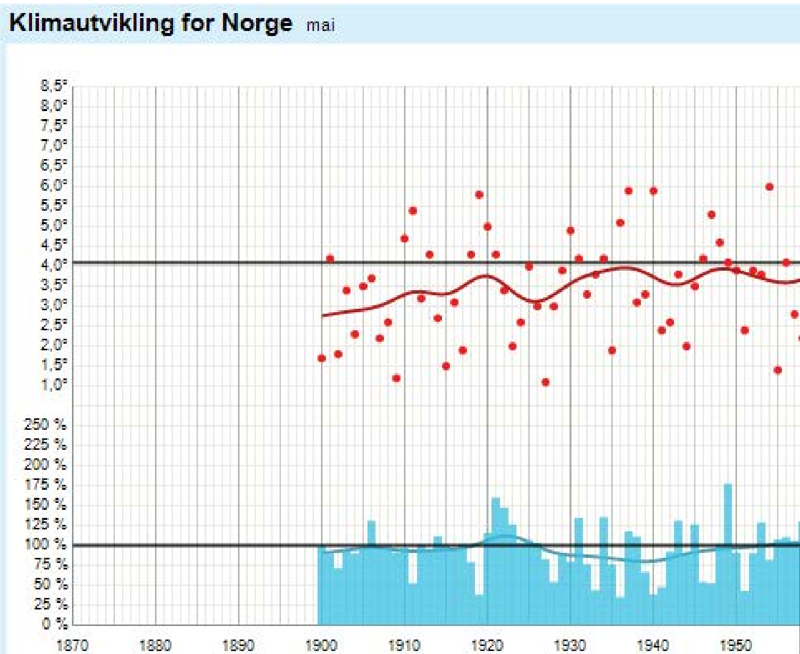
Prolonged dry weather and heavy wind

**Winter drought causing extreme wildfires**

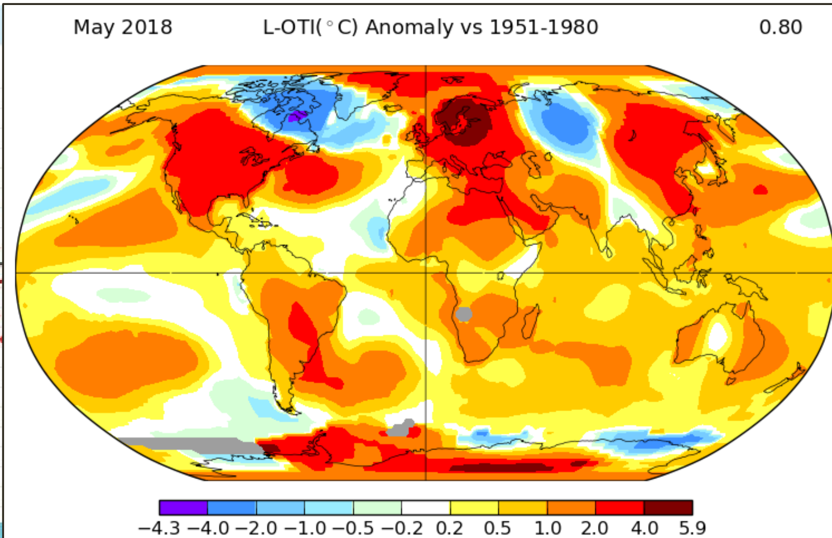
- Greening – biomass
- Reduced snow cover
- Ignition

*DSB rapport 2014*

# Extreme hot and dry summer 2018




*Kilde: Meteorologisk Inst.*

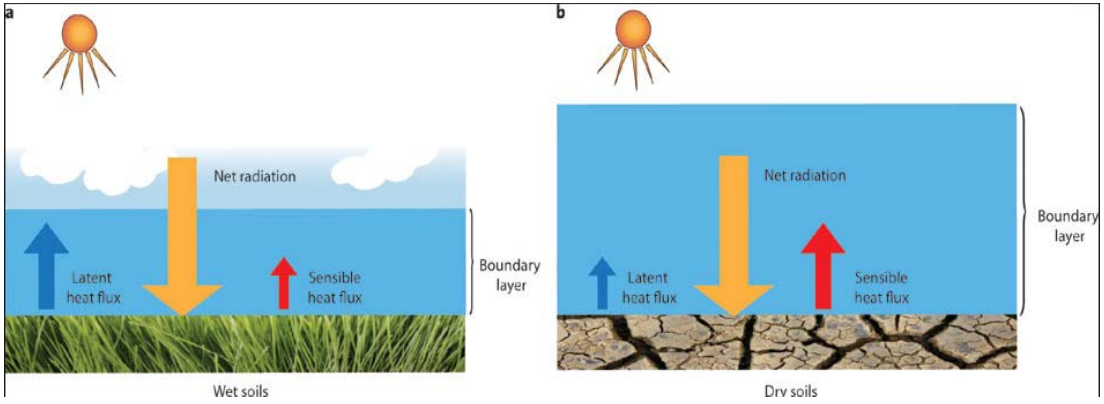



Europe: warmest **May** (since1910) with 2,76 °C above normal

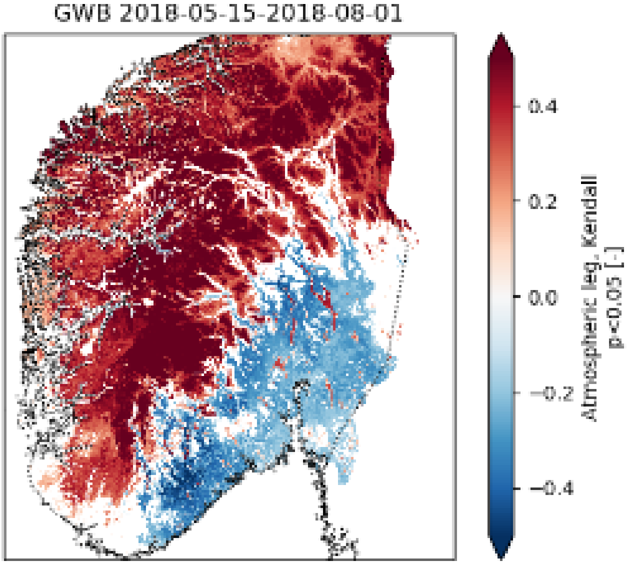
*https://data.giss.nasa.gov/gistemp/maps/*

See poster, Bakke et al.

# Drought and heatwaves



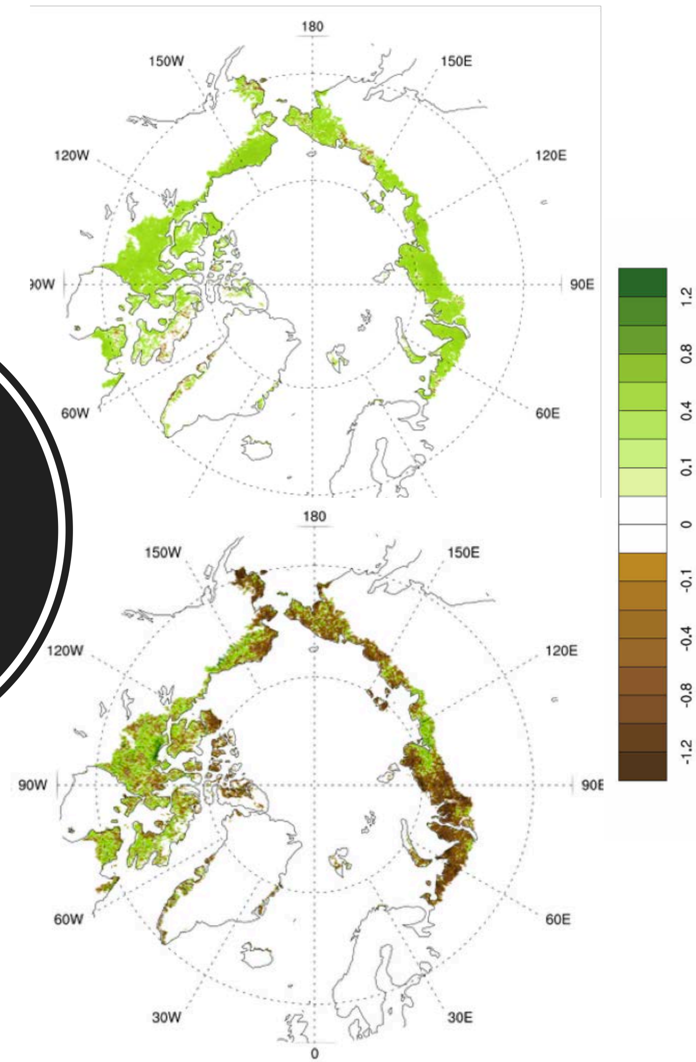

*https://rgsweather.com/tag/soil-moisture/*




*Erlandsen, Brox-Nilsen et al. (work in progress)*

# Arctic Greening and Browning

Ti-NDVI 1982-1998




Ti-NDVI 1999-2013

- High-latitude warming has led to a **greening** of the Arctic up until the early 21st century.
- Despite further warming, strong **browning** signals appeared in recent years.
- **Extreme winter events** and **snow** cover change may be the cause.

- At UiO two RCN-funded projects address this issue:

WINTERPROOF (Parmentier)

EMERALD (Stordal)

# Heavy rainfall and flashfloods

## Skader fra styrtregn har økt med 800 prosent siden 1990-tallet

I helga er det igjen fare for flom. Nå kritiserer Miljøpartiet De Grønne regjeringen for å sende ansvaret for å løse problemene til kommunene.

Brannmannskapene fra Fredrikstad måtte ta gummibåter i bruk for å hjelpe folk etter styrtregnet forrige helg.
FOTO: MAY IREN BERG

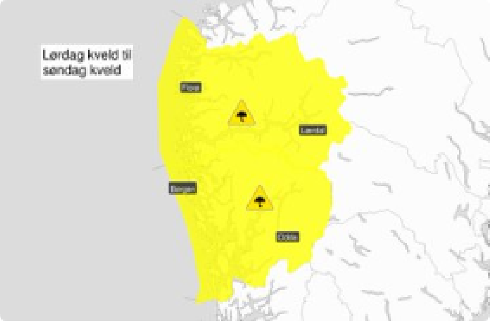
Christian Nicolai Bjørke
Journalist

Publisert 6. sep. kl. 17:19
Oppdatert 6. sep. kl. 18:53

**Fredag kveld og lørdag skjer det igjen:** Meteorologene varsler om tidvis store nedbørsmengder på Østlandet. De kraftigste skyene kommer først inn over Oslofjorden fredag kveld, beveger seg nordover forbi Oslo og inn i Sverige lørdag formiddag. Det ventes mellom fem og ti millimeter regn på en time. Siden elver og vassdrag allerede er fulle, har NVE sendt ut gult farevarsel.

**Meteorologene**
@Meteorologene

Vi har sendt ut gult farevarsel for nedbøren i helgen. Fra lørdag kveld til søndag kveld er det ventet lokalt 60 til 100 millimeter på 24 timer i #Hordaland og #SognOgFjordane. Hold deg oppdatert på yr.no/farevarsel ⚠️




1

**Nedgradert: Varsel om jord- og flomskredfare, grønt nivå for Hordaland, Sogn og Fjordane og deler av Møre og Romsdal** (NVE)

Gyldig for: 2019-09-12. Publisert: 12.09.2019 kl. 12.58. Neste varsel før: 13.09.2019 kl. 11.00

Oppdatert informasjon - 12.09.2019 kl. 09.42

Varsel for Hordaland, Sogn og Fjordane og deler av Møre og Romsdal er nedgradert til grønt pga nedjusterte nedbørprognoser.

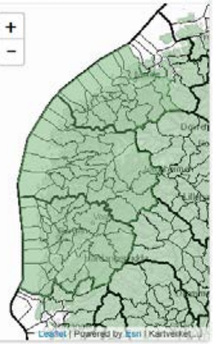
Type
Jordskred

Det ventes regn og stedvis kraftige regnbyger fra torsdag ettermiddag, opp mot 50-80 mm/24t og lokalt opp mot 30-50mm/6t. Grunnvannstanden og vannmetningsgraden i bakken er stedvis høy. Nedbørmengden og nedbørens plassering er usikker. Skredfaren er størst der bygene treffer. Følg værradar.

Bratte skråninger, samt bekker og elveløp med stor vannføring er spesielt utsatt. Varselet ligger i nedre del av gult nivå.

Søk etter sted eller område

Kart
Oversiktskart



# Lessons Learned - the 2001/2002 Canadian Drought


*Wheaton et al. (2005)*

# Extreme event attribution

**Media**
What is the role of global warming in this year summer drought?

© Stock image

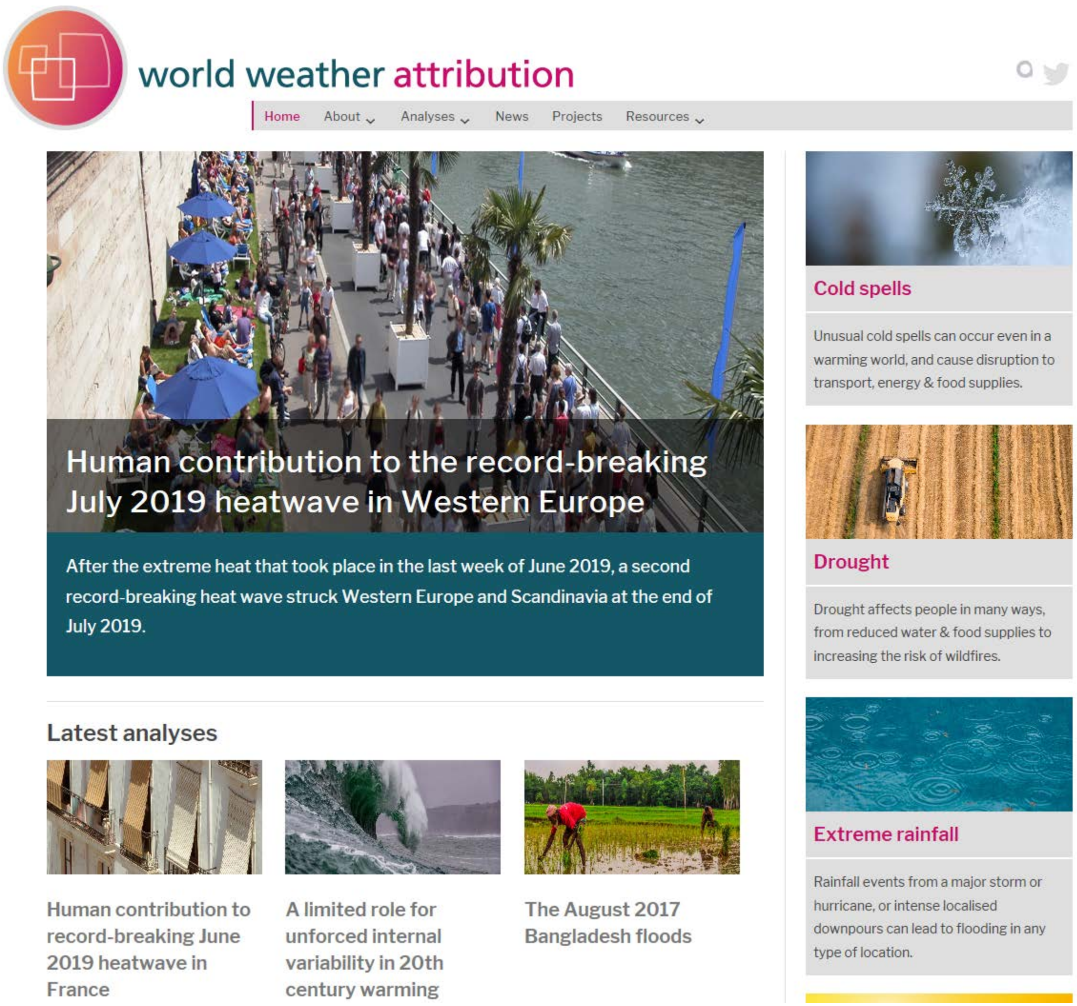
**Scientist**
Can now assess how global warming may have impacted the probability or magnitude of individual events;

*2000 Flood UK:*
the risk of floods occurring in autumn 2000 increased by more than 20%
(Pall et al., 2001)

*2018 Drought:*
the probability to have such a heat or higher is generally more than two times higher today.

# Attribution

*www.worldweatherattribution.org*



# Some key messages …

- Conventional **frequency analysis** offer little insight into governing processes and how they shape the distribution
- **Extreme impacts** result from complex multivariate interactions
- Need robust **indicators** tailored for different sectors (and impacts)
- Increased effort on assessing the **impacts of compound events** under global warming
- Balance between **in-depth studies** of recent events vs integrated, regional analyses
- Need to **adapt** to a changing climate
- Awareness that **future extremes** may be **unpreceeded**.

UiO : Department of Geosciences
University of Oslo

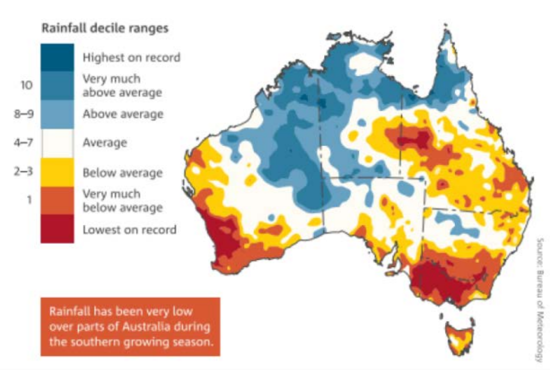

*FLIUP.com*

# Thanks for the attention!

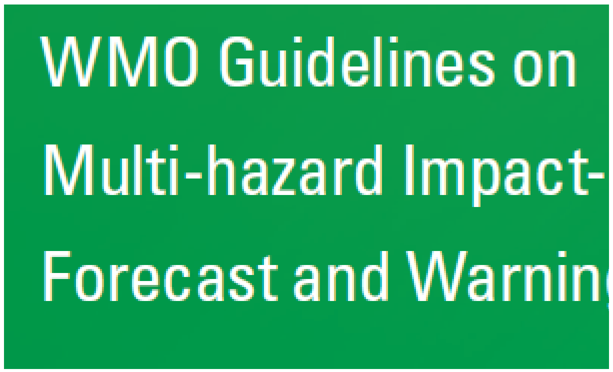
Lena M. Tallaksen

***5th Conference on Modelling Hydrology, Climate and Land Surface Processes***
*Lillehammer, Norway*
*17-19 September 2019*

# Additional slides



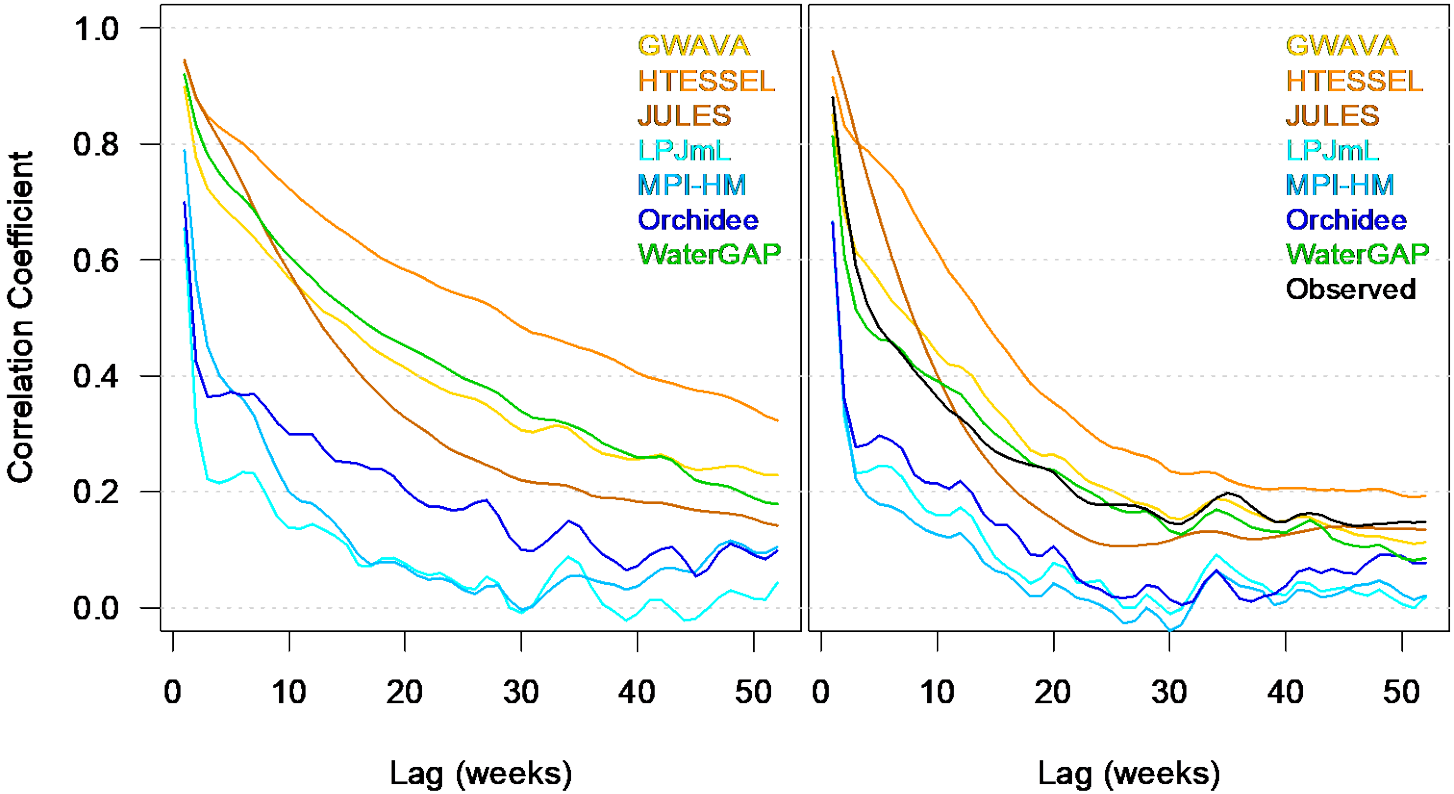
# Impact-based forecasting - projections




Gap between forecasts
hydrometeorological e
their potential impact

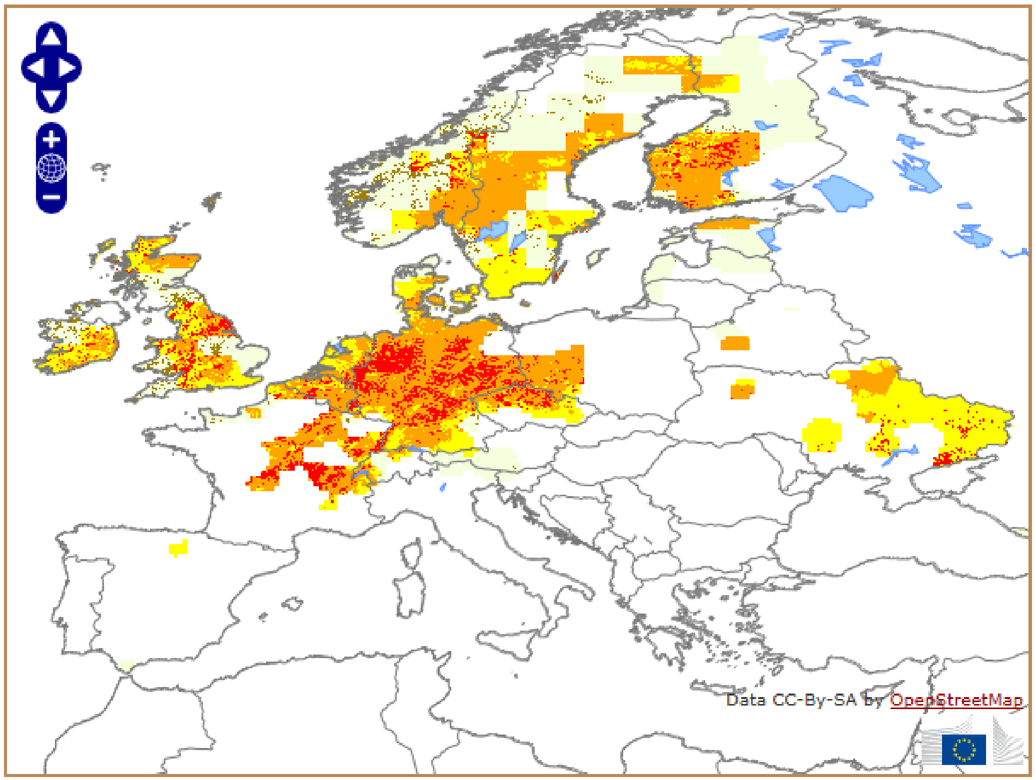
| Evolving warning paradigm using a heavy rain event as an example | | Factors incorporated |
|---|---|---|
| General forecast | A cold, windy, wet day tomorrow with spells of very heavy rain expected in the afternoon and evening. | Hazard |
| Warnings with fixed thresholds | Rainfall accumulations of 30 mm to 40 mm expected tomorrow between 1400 and midnight. | Hazard |
| Warnings with user-defined thresholds | Heavy rain expected tomorrow afternoon with rainfall intensities of 3 mm/10 mins possible, leading to overflow in the drainage system. *(Note that this type of warning would typically be issued to a municipal authority only.)* | Hazard Vulnerability |
| Warnings with spatial and/ or temporal variations in thresholds | Spatial differences: Weather warning – rainfall accumulations of 20 mm to 30 mm expected tomorrow in low-lying areas between 1400 and midnight, with accumulations of 50 mm to 60 mm possible at altitudes above 1 500 m. Temporal differences: Weather warning – rainfall accumulations of 15 mm to 20 mm expected tomorrow afternoon during rush hour. *(Note the lower threshold at times when the roads will be very busy.)* | Hazard Vulnerability |
| Impact-based warning | Rainfall accumulations of 20 mm to 30 mm expected tomorrow between 1400 and midnight, resulting in possible road closures due to flooding across the south-east. *(Note the subtle but important distinction between the impact-based warning and the threshold warning described above. The distinction is that the threshold-based warnings only specified generalized flooding; the impact-based warning provided specific mention of an impact, in this case road closures.)* | Hazard Vulnerability |
| Impact warning | Expect journey times on the A111 likely to be lengthened by an hour because of significant traffic disruption in the south-east tomorrow afternoon due to localized flooding which is expected to follow a heavy rain event. | Hazard Vulnerability Exposure |

# Area in drought – weekly persistence




Whole European domain    Grid cells with observations

# Map of Current Droughts in Europe




**2nd ten-day period of September 2018**

| Impact | Level |
|---|---|
| **Watch:** rainfall deficit | 1 |
| | 2 |
| | 3 |
| **Warning:** soil moisture deficit | 1 |
| | 2 |
| | 3 |
| **Alert:** vegetation stress following rainfall/soil moisture deficit | 1 |
| | 2 |
| | 3 |
| | 4 |

Increasing Dryness

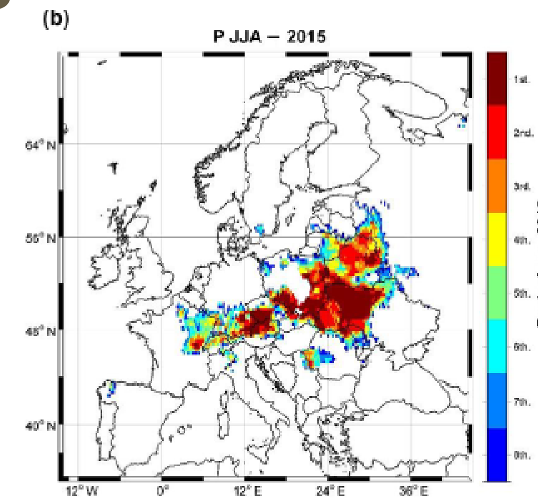
Different dates and/or different indicators

**Combined Drought Indicator**, based on SPI, soil moisture and fAPAR.

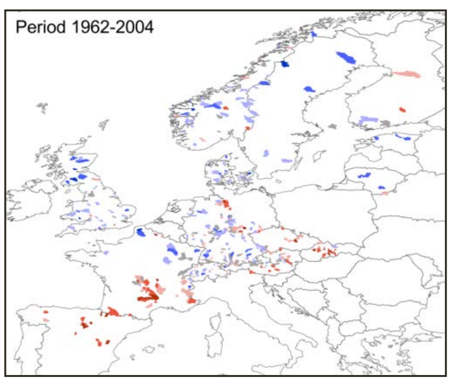
- **Watch**: when a relevant precipitation shortage is observed
- **Warning**: when this precipitation translates into a soil moisture anomaly
- **Alert**: when these two conditions are accompanied by an anomaly in the vegetation condition.

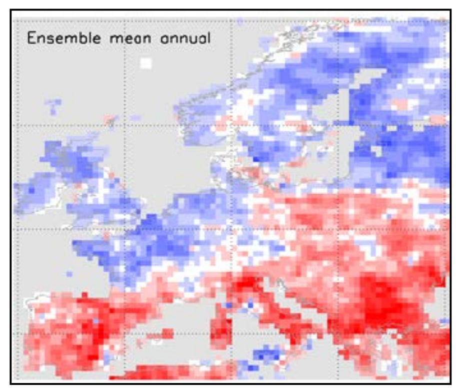
# Example: European scale drought

- Historical events

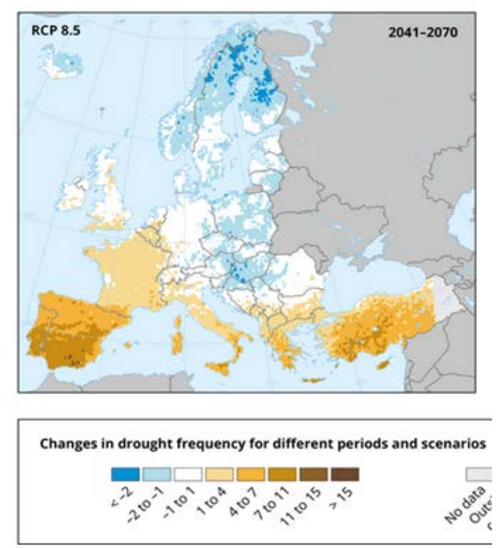


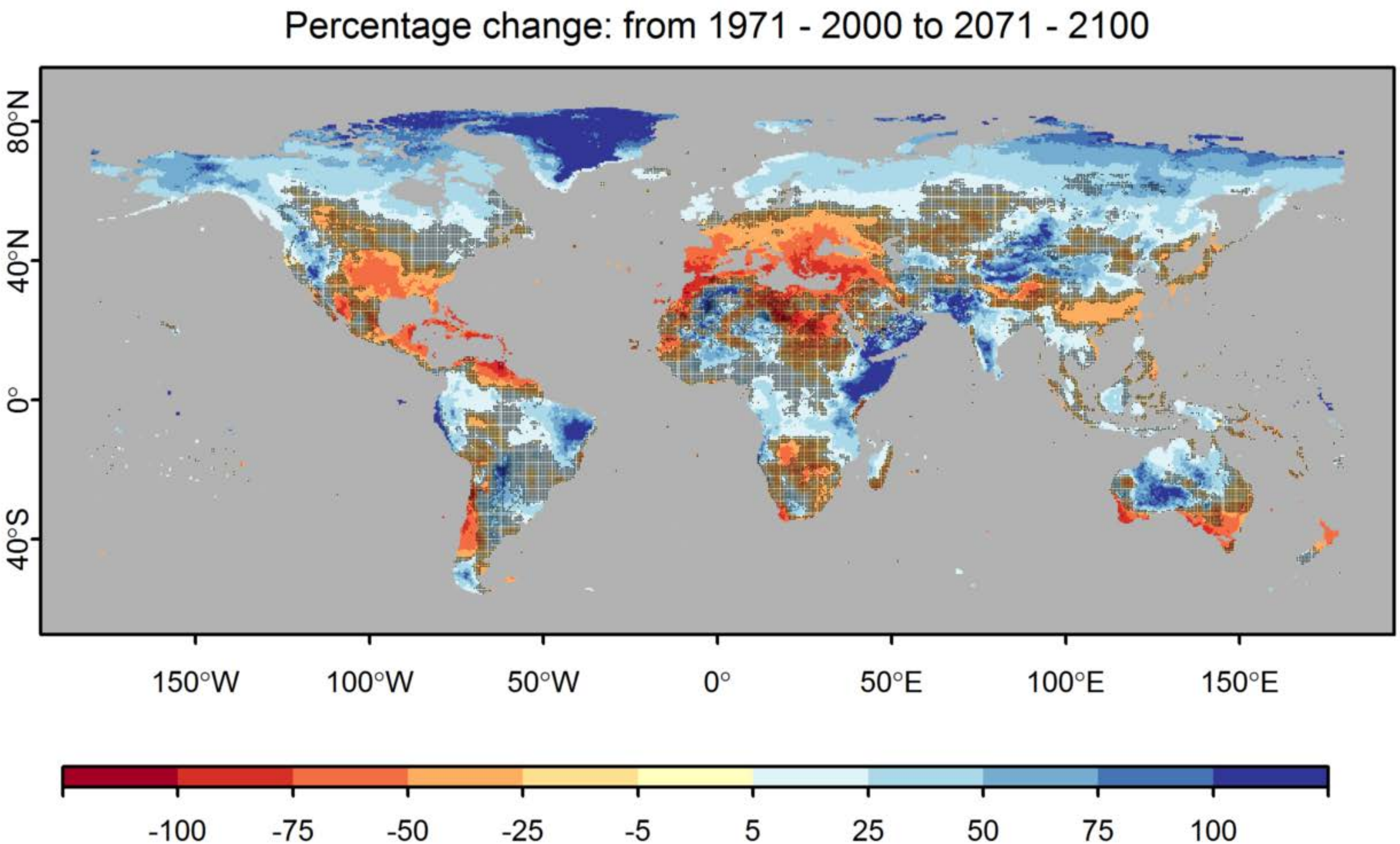

- Current trends and



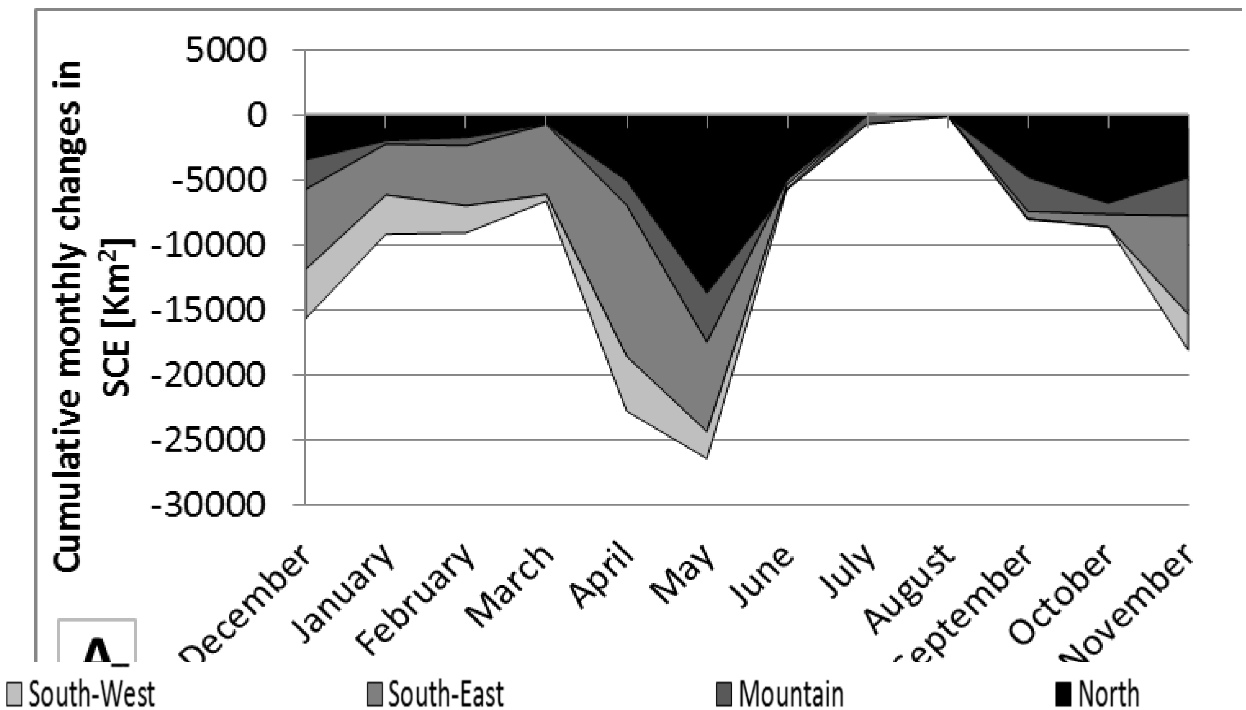

- Future changes






Gudmundsson et al., 2011

# Endringer i snødekket i Norge
## fra 1981–2010 til 1961–1990

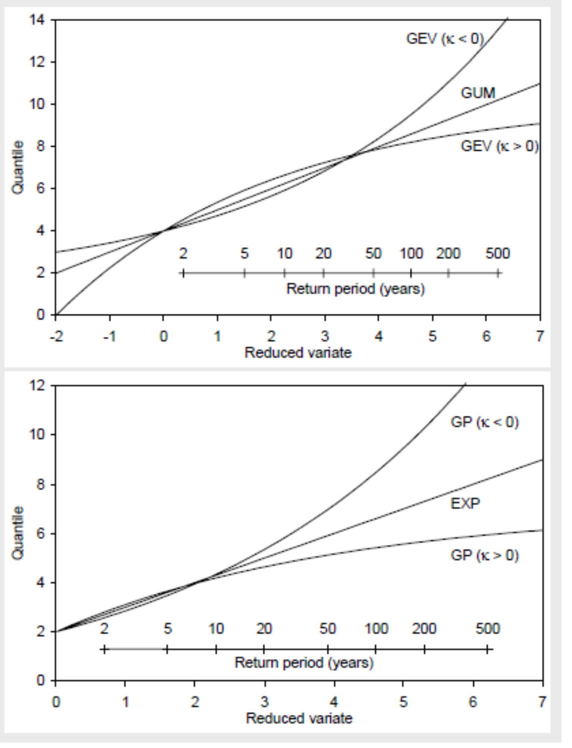



*Rizzi et al., 2017*

# Extreme value distributions

- Choice of distribution governed by the:
  - phenomenon studied
  - theoretical base of EV distributions, i.e. the GEV for AMS and the GP distribution for PDS.
- This might provide a better prediction than can be drawn by merely comparing the fit to the sample.
- The use of regional information will further reduce the sensitivity to sample variability.
- Non-stationary methods include univariate and bivariate models, with distribution parameters varying with time.

*The GEV distribution*

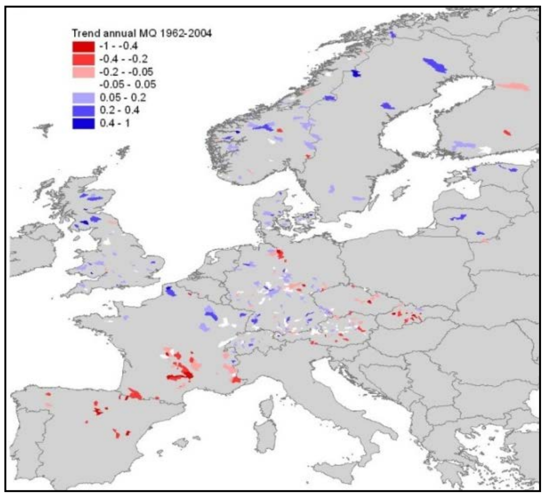


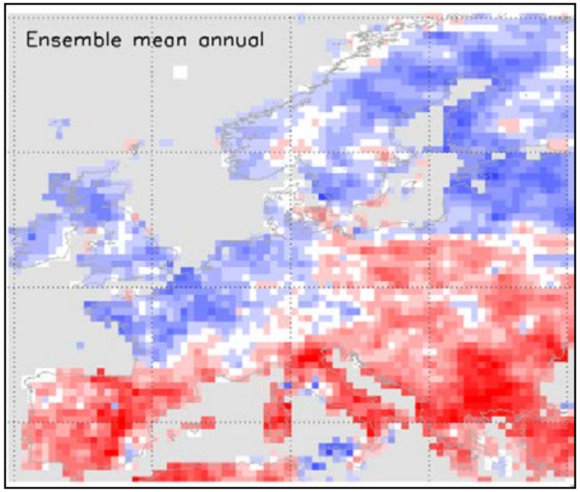

*The GP distribution*

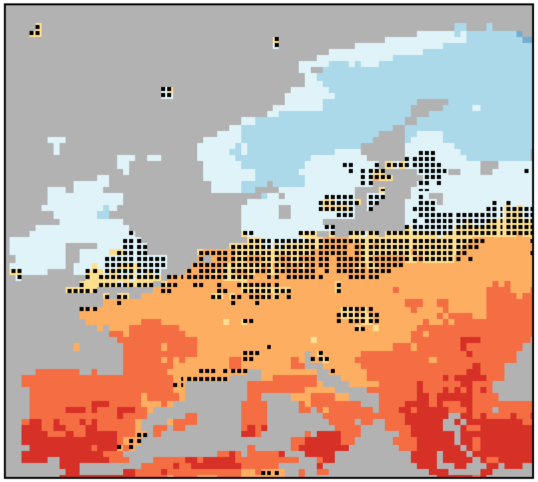
*Tallaksen and van Lanen, 2004*

# European-scale trends and future changes in mean annual streamflow

1962 – 2004




*Stahl et al. (2012)*

*Gudmundsson et al. (2011)*

# Flood event – economic impact

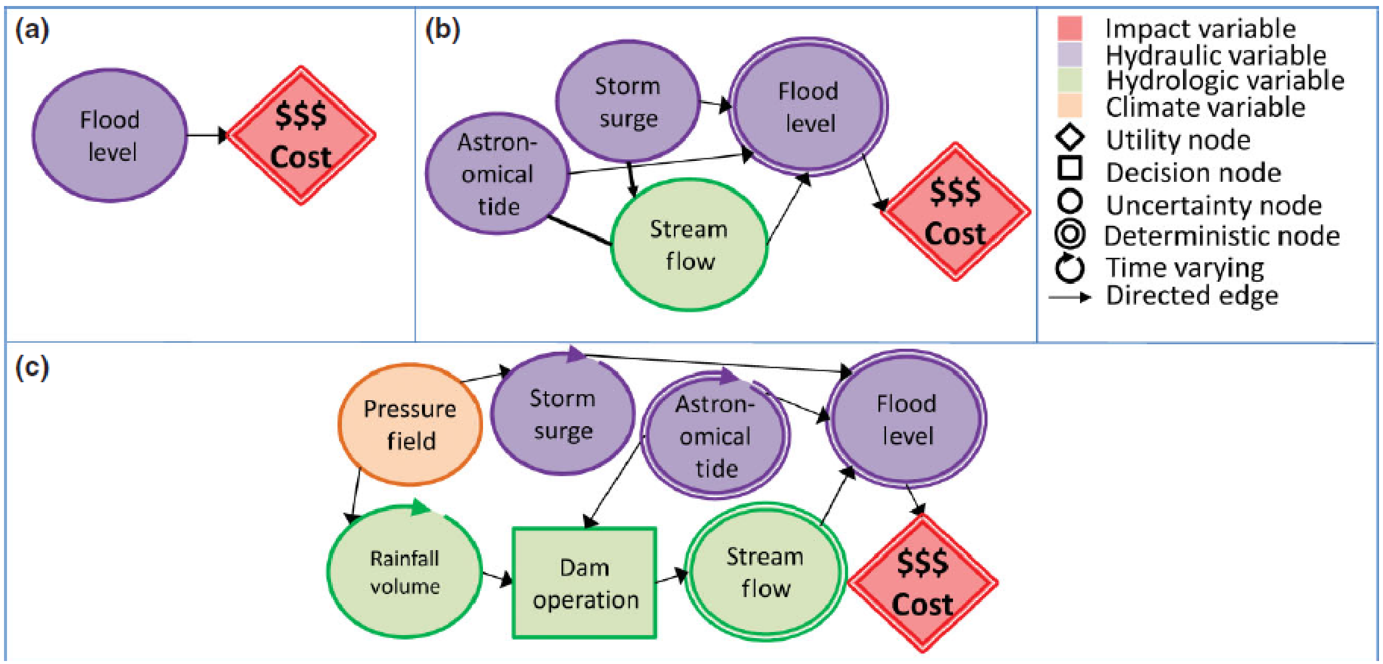



FIGURE 6 | Schematic of a flood event: (a) a univariate probabilistic system; (b) a multivariate probabilistic system; and (c) process model including decision node.

*Leonard et al., 2013*